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Honolulu, Hawaii

The Copper Content of Typical Soils and Plants of the Hawaiian Islands

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Copper is one of the minor elements which has been found to have an important part in the nutrition of plants and animals. The early workers on fungi observed that copper-containing nutrient solutions produced better growth and normal black spores. They attributed the beneficial results to chemical stimulation by copper. Bortels *(5)* obtained decidedly poor growth of *Aspergillus niger* without copper and was probably the first to state that it had a nutritional function in an organism.

In 1931 Sommer *(22)* presented evidence that copper was an indispensable element for the normal growth of tomato, sunflower, and flax. These plants performed normally during the growing period but did not at the fruiting stage in nutrient culture prepared from purified chemicals and water distilled from a copper still. The plants in identical medium except for the water which was distilled from a pyrex glass still developed marked deficiency symptoms early in the vegetative stage. The same year Lipman and MacKinney *(13)* independently verified Sommer's work with barley plants which were unable to produce seeds without copper. Arnon and Stout *(2)* supplied more proof of the essentiality of copper for normal plant life. Their tomato plants developed severe deficiency symptoms when the copper supply was less than 0.001 mg. to a plant and death resulted when the deficiency was left uncorrected. Ben-

* Formerly known as *Progress Notes.*

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eficial response was obtained by supplying 0.002 mg. of copper. Addition of 20 other elements made no difference. The young plants showing deficiency symptoms recovered when sprayed with dilute copper sulfate solution (0.02 ppm Cu). Similar results were reported by Hoagland *(10)* for plum trees; Piper *(15)* for oats, wheat, flax, and tomatoes; and, Bailey and McHargue *(3)* for tomatoes.

Fruit trees growing on soils where copper is not sufficiently available developed exanthema or dieback disease. Grossenbacker *(8)* reported that this disease on Florida citrus trees could be cured by applying copper sulfate to the soil. Flody *(7)* found spraying Bordeaux mixture was effective in curing dieback. Smith and Thomas *(20)*, and Anderson *(1)* obtained similar results with pears, peaches, plums, apricots, and apples. Haas and Quale *(9)* produced exanthema in Valencia orange trees grown in copper-deficient sand culture.

Copper is also essential for the growth and health of animals. Marston and Lee *(14)* reported that anemia, slow growth, poor off-color coat of cattle, loss of crimp in wool, poor reproductive capacity, and ataxia in sheep are all caused by a deficiency of copper. The South Australian littoral soils where these symptoms occur are calcarious, silicious, and low in copper and the natural grass in this area is a poor source of copper. For maintenance of normal health, each week throughout the year, 3.5 g. copper sulfate was supplied to cattle, and 1.5 g. of copper to individual sheep. Cunningham *(6)* reported that sheep and cattle on New Zealand pastures suffered from similar copper deficiency which was further complicated by the high molybdenum content of the soil. New Zealand soils normally contain 18 to 20 ppm copper, and the pasture grass about 11 ppm copper. Piper *(15)* stated that the most common range of copper in plant materials is from 1 to 20 mg. per kg. of dry matter. He pointed out that very low concentrations of copper will meet the requirements of small plants if the supply is maintained. 0.1 ppm copper is sufficient for maintenance, 0.001 ppm will produce increase in growth, and 2 ppm is toxic.

The copper level in the soil depends on many factors. Peat and muck soils are low in total and available copper; sandy and calcarious soils are low in total copper, and high in weathered basaltic soils. Johnson and Graham *(12)* reported 21 to 82 ppm copper in Missouri soils; Sokoloff *(21)* in his project notes on dispersion of copper in some Hawaiian soils and rocks reported 1 to 200 ppm copper; Shiba *(19)* reported 26 to 150 ppm total copper and 0.5688 ppm available copper in air-dried soils of Japan. According to Sedletsky *(18)*, copper is highest in the clay fraction of the red and yellow subtropical fractions, intermediate in the chernozems, and lowest in the podsols.

This investigation was undertaken with the purpose of determining (a) the copper levels of Hawaiian soils and plants, (b) areas which may be deficient in copper, (c) whether application of copper would increase the production of plant crops, and (d) whether copper deficiency is a partial answer to the scouring of cattle disease in some areas on the island of Molokai during certain times of the year.

Soil and Plant Materials for Analysis

The soils selected for this study were from the different horizons of soil profiles which are representative of the great soil groups occuring in the Hawaiian Islands, and the plant samples in most cases were those found growing on these selected soils. The pH of the surface soils was as follows: low humic latosol, 5.4; humic latosol, 5.0; humic ferruginous latosol, 4.5; and hydrol humic latosol, 5.0. The soils of the tropical reddish prairie had a pH of 6 to 7; soils of the latosolic brown forest, pH 5.5 to 6; and soils of the dark magnesium clay and gray hydromorphic had a pH of 8.2 and 5.8, respectively. The samples were air-dried for several days and representative fractions were ground to a fine powder with a mullite mortar and pestle and kept in stoppered bottles.

Interference of Platinum

The conventional procedure of decomposing soil by fusion with sodium carbonate in platinum crucible was not followed because Bailey and McHargue *(4)* found excessively large amounts of copper in plant materials when the samples were dry-ashed in platinum dishes and the copper determined colorimetrically as copper carbamate. They immediately suspected platinum contamination and proved that pure platinum chloride reacted in the same way as copper with diethyldithiocarbamate, producing a yellow color which was extractable with organic solvents.

Method of Preparing Soil Solutions

Soil samples, 0.2 to 0.4 g., were accurately weighed into 150 ml. Griffin beakers with (watch) glasses for covers and digested with 40 ml. of mixed acids (10 ml. nitric plus 30 ml. hydrochloric) on a hot plate at low heat until foaming was under control, then kept boiling gently until the insoluble matter became light in color, which took from 5 to 20 hours. The time required varied with the type of soil. When the acid seemed no longer effective, the solution was diluted and decanted into another beaker and the residue was digested with more fresh-mixed acids. After the digestion the solutions were combined and evaporated to dryness to remove the nitric acid. The residue was heated with 20 ml. of 2 N hydrochloric acid for about half an hour to dissolve the soluble material and was filtered. The residue and paper were washed with normal hydrochloric acid until the paper was free of yellow stain, then ignited to complete ash. The ash was heated with a little hydrochloric acid to dissolve any soluble matter, decanted, and added to the rest of the solution. The crucible with the insoluble residue which still contained some undecomposed soil was fused with half a gram of sodium carbonate for 1 minute. When cold, the fused mass was dissolved with water and poured into a small beaker, acidified, and added to the rest of the solution. This short fusion had to be done in many cases when the aqua regia treatment did not completely decompose the soil material. Because of the small amount of the undecomposed material and the very short fusion period, the fused material developed no color when tested with the carbamate reagent at pH 8.5. This indicated that although fusion should be avoided the modified procedure was permissible.

The volume of soil solution was kept to about 50 ml., and 10 ml. of 10 percent ammonium citrate was added; the pH was adjusted to 2.5; then the entire solution was transferred to a 125 ml. separatory funnel, and the copper extracted with 5 ml. of 0.01 percent dithizone in carbon tetrachloride by vigorous shaking for 3 to 4 minutes. The tetrachloride layer was drained into a 150 ml. beaker and the extraction was repeated with more dithizone until the tetrachloride layer remained green. The undrained green dithizone was extracted with 2 ml. of carbon tetrachloride and added to the copper dithizone portion. The tetrachloride solution was evaporated to dryness and the copper dithizonate was oxidized to a whitish residue with 2 ml. of concentrated sulfuric acid and 1 ml. of perchloric acid on the hot plate. When fuming ceased, the beaker was heated with a burner to remove the last trace of perchloric acid. The residual copper sulfate was taken up with 20 ml. of normal hydrochloric acid, digested for 15 minutes, cooled to room temperature, diluted to 40 ml. with water, and from here on the solution was treated in the same manner as the standard copper solution as described in the following section. Blanks were run simultaneously with the sample analyses in the reagents in order to correct for contamination. After taking the readings the solutions of copper carbamate were shaken with 2 ml. of 10 percent potassium cyanide. All solutions became colorless, which indicated absence of bismuth.

Procedure for Preparation of Standard Curve

The procedure is a slight modification of the procedures of Sherman and McHargue *(17)*, Holmes *(11)*, and Piper *(16)*. A stock copper sulfate solution was prepared by dissolving 0.3930 g. of crystalline copper sulfate ($CuSO_4 \cdot 5H_2O$) ACS reagent grade, in water containing 5 ml. of concentrated sulfuric acid and diluted to 1 liter according to Piper's directions. From this stock solution 10 standard solutions ranging in copper from 0.001 to 0.1 mg. were made, and the copper carbamate color was developed for the reference curve as follows: The copper solution was diluted to 40 ml. with water, 5 ml. of 10 percent ammonium citrate was added, and the pH was adjusted to 8.5 to 9 with ammonium hydroxide by means of a Beckman pH meter. The solution was immediately transferred to a 125 ml. separatory funnel; 1 ml. of 0.1 percent sodium diethyldithiocarbamate and 6 to 7 ml. n-butyl alcohol were added and vigorously shaken for 3 to 4 minutes and left to separate into two phases. The aqueous portion was drained into another separatory funnel and extracted again with 4 ml. of butyl alcohol. The alcohol portions were drained into a 40 ml. centrifuge tube, the funnels were rinsed with 2 ml. of n-butyl alcohol, the rinsing combined with the rest, and the volume made to 10 ml. The well-mixed solution was transferred to a colorimeter tube, and the color transmittancy was determined in a Klett-Summerson photo colorimeter with a blue filter having a maximum transmittancy of light at 420-angstrom wave length. The readings of the standard solutions from 0.01 to 0.06 mg. gave a straight line, but between zero and 0.01 mg. the curve was slightly curved. The yellow color of copper carbamate remained unchanged over 10 hours.

The copper content of the soil samples is presented in table 1. The copper content of the soils ranged from 16 to 357 parts per million. The amount of copper in the soil is not related to the stage of weathering, as the highly weathered soils of the humic ferruginous latosols are represented by the highest and lowest copper contents of the profile analyses. It is more likely that the nature of the original rock played an important role in the copper content of the soils. The lowest copper content was found in the soils formed on trachyte as represented by the analysis of the samples from the Naiwa family from Wailuku, Maui, the copper content of which ranged from 12 to 35 parts per million. The highest content of copper was found in the soils developed from olivine basalt and basaltic volcanic ash such as the Naiwa profile from Kokee, Kauai, and the Kahana profile from Lihue, Kauai. The soils developed on the less basic flows such as andesitic flows have an intermediate copper content.

TABLE 1. Copper content of typical soil profiles representing the dominant great soil groups of the Hawaiian Islands

Depth (inches)	Location	Island	Great soil group	Soil family	Ppm copper
0-8	Makaweli	Kauai	Low humic latosol	Molokai	144
8-17	"	"	"	"	138
17-33	"	"	"	"	126
33-48	"	"	"	"	116
48 +	"	"	"	"	117
0-8	Pearl City	Oahu	Low humic latosol	Molokai	206
8-18	"	"	"	"	121
18 +	"	"	"	"	148
0-15	Lihue	Kauai	Low humic latosol	Kahana	355
15-20	"	"	"	"	357
20-26	"	"	"	"	273
26-37	"	"	"	"	178
37-52	"	"	"	"	156
52 +	"	"	"	"	120
0-1	Kawailoa	Oahu	Low humic latosol	Kahana	204
1-6	"	"	"	"	255
6-10*	"	"	"	"	71
10-24	"	"	"	"	84
24 +	"	"	"	"	130
0-10	Poamoho	Oahu	Low humic latosol	Wahiawa	298
10-21	"	"	"	"	238
21-42	"	"	"	"	219
42 +	"	"	"	"	220
Surface	Waimanalo	Oahu	Low humic latosol	Waimanalo	65
Subsurface	"	"	"	"	72

* Unconformity.

TABLE 1. *Continued*

Depth (inches)	Location	Island	Great soil group	Soil family	Ppm copper
0-10	Waialua	Oahu	Low humic latosol	Waialua	116
10-24	"	"	"	"	102
24 +	"	"	"	"	96
0-2	Kokee	Kauai	Humic ferruginous latosol	Naiwa	226
2-4	"	"	"	"	344
4-10	"	"	"	"	371
10-12	"	"	"	"	223
12-24	"	"	"	"	100
24 +	"	"	"	"	228
0-8	Wailuku	Maui	Humic ferruginous latosol	Naiwa	31
8-14	"	"	"	"	35
14-20	"	"	"	"	28
20-40	"	"	"	"	92
40 +	"	"	"	"	17
Rock core	"	"	"	"	16
Titaniferrous concretions	Haiku	Maui	Humic ferruginous latosol	Naiwa	175
"	"	"	"	"	174
0-8	Pauwela	Maui	Humic ferruginous latosol	Haiku	134
8-14	"	"	"	"	137
14-17	"	"	"	"	86
17-26	"	"	"	"	77
26-42	"	"	"	"	103
42 +	"	"	"	"	98
0-6	Waialua Falls	Kauai	Humic ferruginous latosol	Puhi	73
6-8	"	"	"	"	80
8-24	"	"	"	"	123

(Continued)

TABLE 1. *Continued*

Depth (inches)	Location	Island	Great soil group	Soil family	Ppm copper
0-10	Kunia Road	Oahu	Humic ferruginous latosol	Manana	106
10-16	"	"	"	"	69
16-24	"	"	"	"	65
24-27	"	"	"	"	54
27-28	"	"	"	"	46
0-8	Kaneohe	Oahu	Humic latosol	Kaneohe	185
8-24	"	"	"	"	184
24-34	"	"	"	"	171
0-12	Hakalau	Hawaii	Humic latosol	Ookala	80
12-40	"	"	"	"	74
40-60	"	"	"	"	72
0-12	Akaka Falls	Hawaii	Hydrol humic latosol	Akaka	58
12-24	"	"	"	"	85
24-32	"	"	"	"	99
32-38	"	"	"	"	74
38-50	"	"	"	"	96
Surface	Hilo Sugar Co.	Hawaii	Hydrol humic latosol	Hilo	155
Surface	"	"	"	"	159
0-9	Kukaiau	Hawaii	Latosolic brown forest	Hanipoe	53
9-12	"	"	"	"	96
12-15	"	"	"	"	57
15-23	"	"	"	"	52
0-9	Kukaiau	Hawaii	Latosolic brown forest	Maile	60
9-18	"	"	"	"	37

(Continued)

TABLE 1. *Continued*

Depth (inches)	Location	Island	Great soil group	Soil family	Ppm copper
0-6	Lualualei	Oahu	Dark magnesium clay	Lualualei	112
6-15	"	"	"	"	90
0-6	Honouliuli	Oahu	Gray hydromorphic	Honouliuli	43
6-14	"	"	"	"	47
0-6	Honouliuli	Oahu	Gray hydromorphic	Kaloko	163
6-12	"	"	"	"	160
0-6	Kalihi	Oahu	Gray hydromorphic	Kalihi	155
6-12	"	"	"	"	159
Surface	Koko Head	Oahu	Reddish brown	Waikaloa	115
Surface	"	"	"	"	108
0-6	Kula	Maui	Tropical reddish prairie	Waimea	53
6-12	"	"	"	"	54

PLANT ANALYSIS

All plant materials were washed under running water, rinsed liberally with distilled water, drained, cut into small pieces, spread on cheesecloth, and dried at 75° to 80° C. in a drying oven with an upward forced draft until crisp. The dried material while hot was ground with a mullite mortar and pestle and kept in stoppered bottles.

Samples weighing from 2 to 5 g. were put in 800 ml. Kjeldahl flasks and wet-ashed by Piper's procedure *(14)*. The material was first digested slowly with 25 ml. nitric acid about half an hour until foaming decreased, then 15 ml. sulfuric acid were carefully added, and the digestion was continued. When the digestion was more than three-fourths done, carbonization began to increase and this was kept to a minimum by adding a few drops of nitric acid. When the solution was light in color a few drops of perchloric acid were added and heated until practically colorless. The total time of digestion was about 2½ hours per sample. The solution was cooled, diluted with 50 ml. water, transferred to a 250 ml. beaker, and evaporated until fuming of the acids ceased. The residue was heated for about 15 minutes with normal hydrochloric acid, filtered through an acid-washed filter, and washed with five 5 ml. portions of normal hydrochloric acid. From here on the filtrate was treated in the same manner as the soil solution and the same standard curve was referred to for the copper content. Blanks were similarly treated for corrections. The results of the analysis are tabulated in table 2.

The data presented in table 2 show a wide range of copper content in the tissue of plants ranging from 1.2 to 31 parts per million. The plants grown on soils developed on completely weathered geological material and containing little or no primary minerals, had a higher content of copper than those which contained appreciable amounts of unweathered rock materials. Even in each of these cases the range was very wide and not too conclusive. Sugar cane leaves are good examples; i.e., sugar cane grown on soils of the Low Humic Latosol group contained 31, 31, 15, 15, and 11 parts per million of copper; and when grown on soils of the Dark Magnesium Clay and Gray Hydromorphic groups they contained 7, 6, and 8 parts per million of copper.

TABLE 2. Copper content of whole plants or parts grown on different Hawaiian soils

Name of plant	Location	Island	Great soil group	Soil family	Ppm copper
Natal red top grass *Tricholaena repens*	Kokokahi	Oahu	Humic latosol	Kaneohe	12.0
Napier grass *Pennisetum purpureum*	Kokokahi	Oahu	Humic latosol	Kaneohe	9.7
Vasey grass *Paspalum urvillei*	Kokokahi	Oahu	Humic latosol	Kaneohe	12.2
Sweet potato leaves *Ipomoea batatos*	Poamoho	Oahu	Low humic latosol	Wahiawa	15.5
Sweet potato root	Poamoho	Oahu	Low humic latosol	Wahiawa	7.0
Tomato fruit *Lycoperium esculentum*	Poamoho	Oahu	Low humic latosol	Wahiawa	30.5
Spinach leaves *Amaranthus gangeticos*	Poamoho	Oahu	Low humic latosol	Wahiawa	15.2
Pole beans, green pods *Phaseolus vulgaris*	Poamoho	Oahu	Low humic latosol	Wahiawa	7.0
Napier grass	Poamoho	Oahu	Low humic latosol	Wahiawa	15.0
Alfalfa, leaves and stems *Medicago sativa*	Poamoho	Oahu	Low humic latosol	Wahiawa	12.0
Koa haole leaves *Leucaena glauca*	Poamoho	Oahu	Low humic latosol	Wahiawa	10.0

(Continued)

TABLE 2. *Continued*

Name of plant	Location	Island	Great soil group	Soil family	Ppm copper
Sugar cane sheath *Saccharum officinarum*	Puunene	Maui	Low humic latosol		31.0
Sugar cane leaves	Puunene	Maui	Low humic latosol		31.0
Sugar cane leaves	Waialua	Oahu	Low humic latosol	Waialua	15.0
Sugar cane leaves	Kawailoa	Oahu	Low humic latosol	Kahana	11.0
Avocado fruit *Persea Americana*	Lahaina	Maui	Low humic latosol		11.9
California grass *Panicum purpurascens*	Helemano	Oahu	Low humic latosol	Wahiawa	9.0
Pili grass *Heteropogan contortus*	Helemano	Oahu	Low humic latosol	Wahiawa	9.0
Sweet vernal grass *Anthoxanthum odorantum*	Helemano	Oahu	Low humic latosol	Wahiawa	10.0
Sugar cane leaves	Helemano	Oahu	Low humic latosol	Wahiawa	15.0
Native koa leaves *Acacia Koa*	Kokee	Kauai	Humic ferruginous latosol	Naiwa	7.2
Silver oak leaves *Gravillea robusta*	Kokee	Kauai	Humic ferruginous latosol	Naiwa	2.0
Japanese tea leaves *Cassia leschenaultiana*	Kokee	Kauai	Humic ferruginous latosol	Naiwa	3.5

(Continued)

TABLE 2. *Continued*

Name of plant	Location	Island	Great soil group	Soil family	Ppm copper
Rice grass *Paspalum obiculare*	Kokee	Kauai	Humic ferruginous latosol	Naiwa	9.7
Crotoleria leaves *Crotolaria muranata*	Makaha Valley	Oahu	Dark magnesium clay	Lualualei	7.2
Koa haole	Makaha Valley	Oahu	Dark magnesium clay	Lualualei	4.8
Pidgeon pea leaves *Cajanus cajan*	Makaha Valley	Oahu	Dark magnesium clay	Lualualei	12.0
Sugar cane leaves	(abandoned field) Makaha Valley	Oahu	Dark magnesium clay	Lualualei	7.2
Tomato fruit	Makaha Valley	Oahu	Dark magnesium clay	Lualualei	13.0
Tomato fruit	Lualualei	Oahu	Dark magnesium clay	Lualualei	22.8
Lettuce	Lualualei	Oahu	Dark magnesium clay	Lualualei	18.3
Napier grass	Honouliuli	Oahu	Gray hydromorphic	Kaloko	9.5
Rice grass	Honouliuli	Oahu	Gray hydromorphic	Kaloko	10.1
Sugar cane leaves	(abandoned field) Honouliuli	Oahu	Gray hydromorphic	Kaloko	5.8
California grass *Panicum purpurascens*	Waimanalo	Oahu	Low humic latosol	Waimanalo	3.3

(Continued)

TABLE 2. *Continued*

Name of plant	Location	Island	Great soil group	Soil family	Ppm copper
Sugar cane leaves	Waimanalo	Oahu	Low humic latosol	Waimanalo	8.0
Bermuda grass *Cynodon dactylon*	Waimanalo	Oahu	Low humic latosol	Waimanalo	9.5
Kaimi clover *Desmodium canum*	Waimanalo	Oahu	Low humic latosol	Waimanalo	12.0
Alfalfa	Waimanalo	Oahu	Low humic latosol	Waimanalo	16.0
Oat leaves *Avena sativa*	Waimanalo	Oahu	Low humic latosol	Waimanalo	17.0
Koa haole	Waimanalo	Oahu	Low humic latosol	Waimanalo	10.4
Papaya fruit *Carica* papaya	Waimanalo	Oahu	Low humic latosol	Waimanalo	2.5
Passion fruit rind *Passiflora*	Waimanalo	Oahu	Low humic latosol	Waimanalo	4.0
Kentucky blue grass *Poa pretensis*	Kamuela	Hawaii	Reddish prairie	Waimea	14.2
Kikuyu grass *Pennisetum clandestinum*	Kamuela	Hawaii	Reddish prairie	Waimea	19.0
Lettuce	Near University campus	Oahu	Lithosol	Undifferentiated	12.0
White radish root	Near University campus	Oahu	Lithosol	Undifferentiated	12.9
Radish leaves	"	"	"	"	7.0

(Continued)

TABLE 2. *Continued*

Name of plant	Location	Island	Great soil group	Soil family	Ppm copper
Algaroba leaves *Propopsis chilensis*	"	"	"	"	12.7
Coffee beans *Coffee arabica*	Kona	Hawaii	Lithosol	Undifferentiated	8.0
Coffee leaves	"	"	"	"	10.6
Rice grass	Volcano area	"	"	"	3.0
Head cabbage	"	"	"	"	1.2
Napier grass	University Farm	Oahu	"	"	9.0
Lettuce	"	"	"	"	12.0
Algaroba leaves	Kamalo	Molokai	Alluvial	"	2.4
Algaroba ripe beans	"	"	"	"	4.2
Algaroba leaves	Kawela	"	"	"	5.0
Algaroba leaves	Kaunakakai	"	"	"	5.0

NOTE: The grasses were identified by Edward Y. Hosaka, Specialist in Agronomy, Hawaii Agricultural Extension Service, University of Hawaii.

Effect of Copper Sulfate Applications on the Growth of Plants

There is no publication on the application of copper for treatment or increase in yield of plants grown in Hawaii and no copper deficiency is known. This lack of information was sufficient reason to try trial applications of increments of copper sulfate on different varieties of plants. Three different types of soil were selected for these purposes: (a) Poamoho, a low humic latosol, pH 5, red, and unfertile; (b) Lualualei, a dark magnesium clay, pH 8.3, dark, productive, montmorillonite type, swells on wetting and cracks wide open on drying; and (c) Waimanalo, a low humic latosol, pH 6.3, brown, productive, and somewhat similar to Lualualei. Poamoho soil was treated at the rate of 1 ton per acre of calcium hydroxide and kept moist for 2 weeks before planting. The copper sulfate was incorporated with the NPK (10-25-16) at the time of mixing the soil. The treatments were as follows: 0; 50; 100; 150; 200; 250; 300; 500; and 1,000 pounds of copper sulfate per acre. One-gallon crocks were used as containers and the number of plants per crock varied with the type of plant: lettuce, 2; spinach, 6; radish, 4; alfalfa, 12; and tomato, 4. The crocks were placed on tables in a random manner in a glasshouse; and the plants were grown up to the flowering stage, then harvested, cut into short pieces, dried in an oven with an upward draft until crisp, and stored in bottles for analysis. All treatments were duplicated. Of the five plants tested, only tomatoes showed indications of deriving benefit from the copper application at 50 to 150 pounds per acre level. The plants at this copper level were bigger than the checks in all three types of soil. The tomato plants were planted on July 7 and harvested August 28, 1958. The tomato experiment was repeated on September 14 and completed on October 29, 1958. The results again appeared encouraging in the Poamoho and Waimanalo soils but the plants in the Lualualei soil were not normal due to a water-logged condition. However, the apparently beneficial results obtained in the long summer day were not realized when the experiment was performed in February through April, 1954. The check plants appeared in every respect as good as those with copper. No fruit was harvested in all the trials but it was assumed that if the plants with copper were bigger and more vigorous than the checks the yield would be greater normally.

A field trial was installed at Waimanalo on a soil having a low copper content. The application of copper salts did not improve yields.

Uptake of Copper by Plants

The lettuce, spinach, and tomato plants that were grown in the three different soils with increments of copper were analyzed to determine whether there was any proportionality in the amount of copper taken up and the amount applied. The results are presented in table 3.

It is interesting to note that the three different plants take up approximately the same amount of copper from the three different soils. There is a slightly larger uptake of copper from soils which had larger amounts of copper added but there is no proportionality of uptake to the amount of copper applied. Also, the plants are able to take up almost as much copper from the check soils as from the treated soils. This experiment seems to indicate that the Hawaiian soils can supply sufficient copper for normal growth of plants.

TABLE 3. Uptake of copper by plants planted in three different types of soils with application of copper sulfate

Name of plant	Great soil group	pH	Soil family	Pounds copper/acre	Ppm copper
Spinach	Dark magnesium clay	8.3	Lualualei	0	10.5
"	"	"	"	100	11.0
"	"	"	"	200	11.5
"	"	"	"	500	18.8
"	Low humic latosol	6.3	Waimanalo	0	14.5
"	"	"	"	100	15.0
"	"	"	"	200	16.0
"	"	"	"	500	22.5
"	Low humic latosol w/1 ton of $Ca(OH)_2$	4.9	Poamoho	0	15.2
"	"	"	"	100	20.5
"	"	"	"	200	11.0
"	"	"	"	500	10.8
Lettuce	Dark magnesium clay	8.3	Lualualei	0	16.6
"	"	"	"	100	18.4
"	"	"	"	200	21.0
"	" "	"	"	500	22.6
"	Low humic latosol	6.3	Waimanalo	0	19.2
"	"	"	"	100	18.5
"	"	"	"	200	14.5
"	"	"	"	500	15.0

(Continued)

TABLE 3. *Continued*

Name of plant	Great soil group	pH	Soil family	Pounds copper/acre	Ppm copper
Tomato	Dark magnesium clay	8.3	Lualualei	0	20.8
"	"	"	"	100	23.5
"	"	"	"	200	20.7
"	"	"	"	500	----
"	"	6.3	"	0	19.0
"	"	"	"	100	20.0
"	"	"	"	200	20.0
"	"	"	"	500	22.5
Tomato	Low humic latosol plus lime	4.9	Poamoho	0	25.2
"	"	"	"	100	29.6
"	"	"	"	200	27.0
"	"	"	"	500	20.0

Discussion and Summary

The copper content of the representative types of Hawaiian soils has been found to range from 16 to 357 ppm, and the average for 87 samples is 124 ppm. This is higher than the averages reported in other areas. The copper content is greater in the upper horizons of the soil and decreases with depth. Copper tends to accumulate where iron oxide is high in the old weathered soils. The exchangeable copper ranged from 0.03 to 0.25 ppm in six soils, although they differed widely in texture, pH, and age.

The copper content of plants ranged from 1.2 to 31 ppm. The lowest was in head cabbage grown in cinder soil near the Volcano area and the highest in cultivated sugar cane leaves obtained from Puunene, Maui, by the Hawaiian Sugar Planters' Association Experiment Station. This sample was tested by the spectrographic method at the Sugar Planters' station and reported to contain 31 ppm copper. The average of copper content of 58 plants which include leaves of trees, beans, vegetables, fruits, and grasses is 11.0 ppm.

The characteristic differences in the soils or the application of increments of copper did not make much difference in the uptake of copper by lettuce, spinach, and tomato. However, there was a slight increase in the uptake at the 500-pound application in some cases and those that did not take up more at this concentration showed toxic effects.

The apparently beneficial results of copper applications shown by tomato when grown in the greenhouse in pots could not be obtained when tried under field conditions. From the general appearance of the plants and the yield of fruit there was no significant difference between treatment and no treatment.

The copper content of 18 grass samples from pastures and cultivated fields averaged 11.1 ppm. Since this is well above the minimum requirement of 5 ppm of copper for the normal health of animals, the prospect of copper deficiency in animal green feed may be very remote.

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